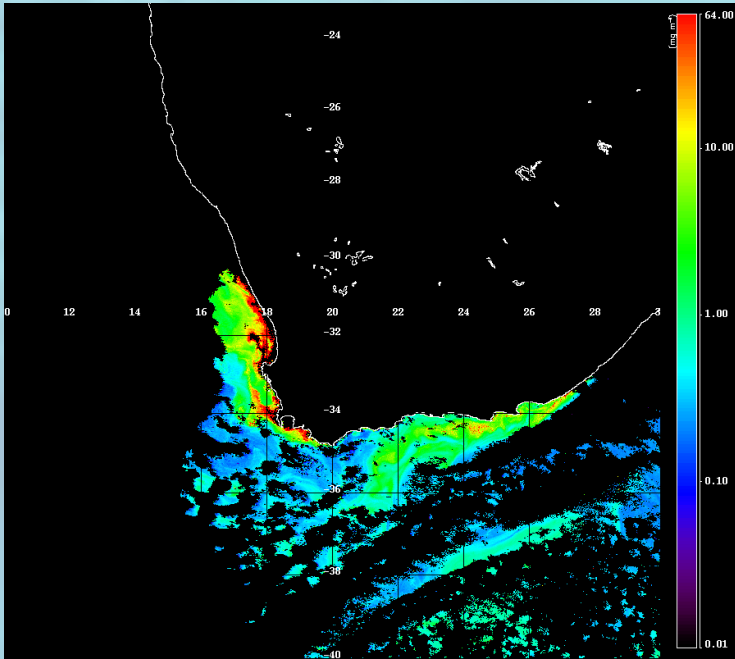
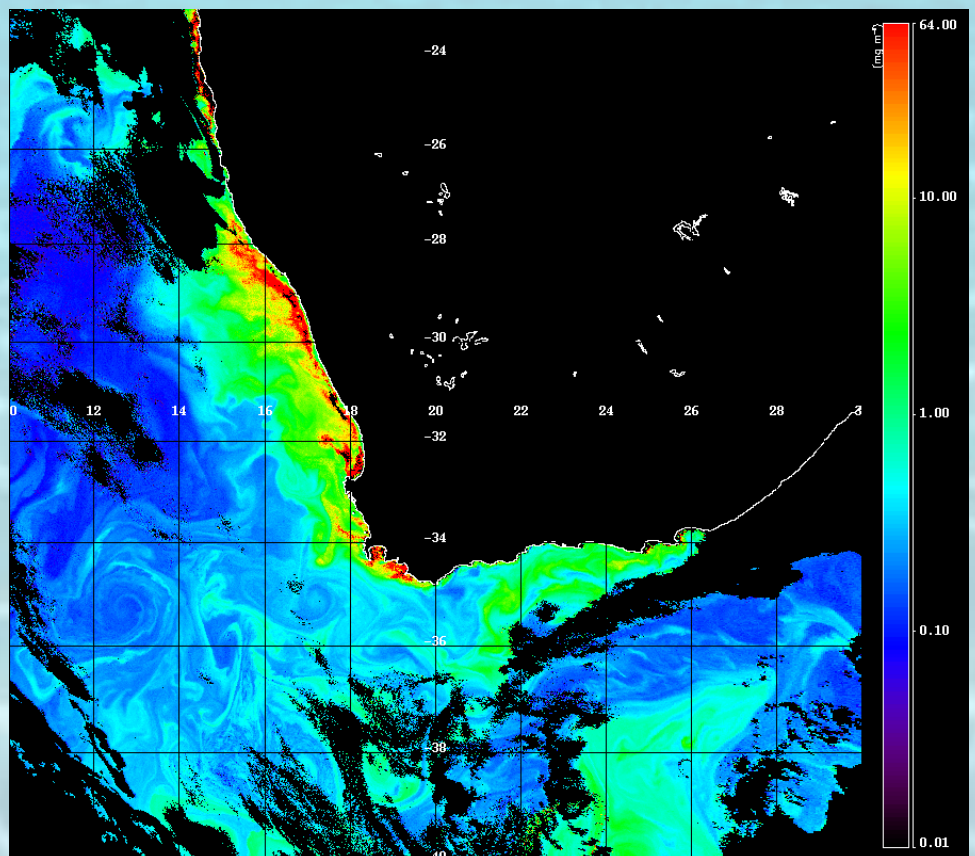


SCIENCE FOCUS: Data Processing

It's Not Easy Being Normal



SeaWiFS images of the Benguela upwelling zone and South African coastal waters, acquired on December 22 (left) and December 23, 1998 (below) from the Pretoria, South Africa, HRPT station (HPRE).



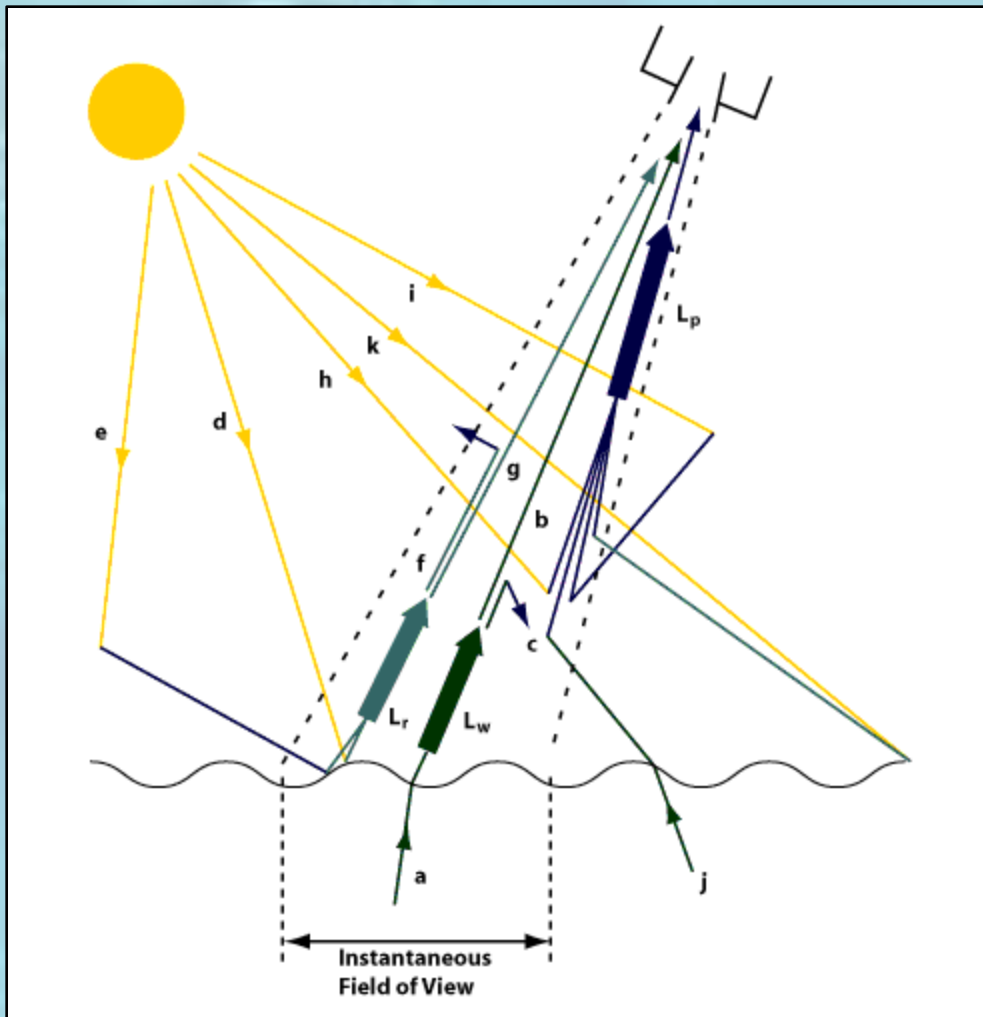
The two SeaWiFS images on the previous page, which show the same region of the coast of South Africa, were obtained on December 22 and 23, 1998. These two images illustrated a question submitted by an ocean color researcher in South Africa, which was: why is there so much less data from the western side of the December 22 image (the upper image)? The answer, which will be found below, is integrally connected to the process of calculating accurate data from satellite ocean color instruments.

No, the answer is not "more clouds". That would be too easy.

It has been stated before, but it bears repeating; SeaWiFS (the Sea-viewing Wide Field-of-view Sensor), MODIS (the Moderate Resolution Imaging Spectroradiometer), MERIS (the Medium Resolution Imaging Spectrometer), OCTS (the Ocean Color and Temperature Scanner), and other ocean color satellite sensors don't actually observe the color of the ocean— what they actually measure are "Earth-leaving radiances" (which is why they are called "radiometers"). So what these orbiting radiometers do is quantify the intensity of light at various wavelengths that is emitted from the area of the Earth that their optical systems are scanning at a given moment in time.

Much of this light actually comes from Earth's atmosphere, not from the surface of the Earth (which could be sand, soil, vegetation, water, ice or snow, pavement, etc.) because sunlight that is reflected off the Earth's surface is scattered by the molecules of the atmosphere numerous times before a small amount of this light escapes to space, where the satellite instrument can detect it. Because the oceans are darker than land, the contribution of light from the atmosphere is greater over the oceans than over land.

The diagram on the next page is an excellent illustration of all the different fates that might befall light from the Sun that shines on the ocean surface.



This diagram is also found in an article in the *Classic CZCS Scenes* series entitled “On the Level: From Radiation to Scientific Imagery”. That article describes how the raw radiances measured by the satellite sensor are processed into Level 1, Level 2, and Level 3 data products. This article only briefly discussed a critical aspect of ocean color data processing, the process of **normalization**. Normalization is the analytical step that transforms the intensity of light measured by a satellite sensor into the geophysical data products called "normalized water-leaving radiances", nLw for short. The nLw values produced by the data processing systems for ocean color instruments are the fundamental data products produced by these sensors and systems. If the nLw values aren't accurate, none of the other data products will be, either. So this *Science Focus!* article will go into a bit more detail about how normalized water-leaving radiances are produced and how this process has evolved since the first ocean color mission, the Coastal Zone Color Scanner (CZCS).

So what exactly is meant by "normalized water-leaving radiance"? Essentially, it's the radiance that would be measured exiting the flat surface of the ocean with the Sun at zenith (directly overhead) and the atmosphere absent. A more technical way to state it is that the water-leaving radiance determined at the satellite is divided by the cosine of the sun angle and the atmospheric diffuse transmittance. Much of the normalization process is referred to as *atmospheric correction*, but the effects of the atmosphere are only part of what must be corrected.

Solar zenith angle calculation

It may seem uncomplicated to calculate for the angle of the sun to produce the theoretical position of the Sun at zenith (directly overhead), but consider this: the correction is performed for a different sun position every day of the year, for each pixel in the satellite swath. Each pixel, which for most ocean color radiometers is 800-1000 meters wide, requires a different solar zenith angle calculation. The processing algorithms calculate the solar zenith angle pixel-by-pixel. SeaWiFS orbits the Earth such that the satellite is overhead at approximately local noon, which minimizes the solar zenith angle. MODIS-Terra and MODIS-Aqua are 1.5 hours ahead and behind local noon. Because the solar zenith angles are larger at those times, the radiance "signal" from the ocean surface is reduced, which makes atmospheric correction a bit more difficult.

If the angle to the sun is quite large, then the solar zenith angle correction may be in error, or the radiance measured by the satellite is too low to be accurate. Data processing identifies pixels with solar zenith angles above a set value, because this data may be less accurate. This condition can be quite significant for data acquired over the polar regions.

Satellite zenith angle calculation

The key to the difference in the two SeaWiFS images shown at the beginning of this article is similar to the solar zenith angle correction. On December 23, the satellite was almost directly overhead Cape Town and the Benguela upwelling system. But on the day before, December 22, the satellite was much further to the east, so that this area was located near the edge of the satellite scanning swath, rather than near the center. That difference meant that the angle from the pixels located at the edge of the scan to the satellite was quite large. Therefore, these pixels were excluded from the calculation of the chlorophyll concentration, because the atmospheric correction algorithm is not sufficiently accurate for this observational geometry.

The primary reason for the reduction in accuracy at large satellite zenith angles is that atmospheric correction becomes more difficult. At large satellite zenith angles, the satellite receives a larger amount of light scattered from the atmosphere (because the light is traveling through a longer light path to the satellite) and a correspondingly smaller amount of signal from the ocean surface, which is what the instrument is trying to measure.

Atmospheric Correction: Rayleigh scattering

It's a classic question—why is the sky blue? (And the follow-up: Why is the ocean blue?) The answer is the same for each question: Rayleigh light scattering, which is the scattering of light by the molecules composing the atmosphere or the ocean. It is explained and illustrated quite well on this Web page: [Blue Sky](#).

The most significant aspect of Rayleigh scattering with respect to atmospheric correction is that it is the predominant mode of scattering for clear-sky conditions. When there is more in the air than just air, the situation is more complicated.

Atmospheric correction: Aerosol scattering

Aerosols are particles in the atmosphere: dust, smoke, volcanic ash, even tiny crystals of sea salt cast into the atmosphere by breaking bubbles of sea foam. The presence of any of these particles will also scatter light, in a manner called Mie scattering. (This is also explained and diagrammed on the linked Web page [Blue Sky](#).)

MODIS uses an atmospheric correction algorithm that was developed and tested using SeaWiFS data. The algorithm employs a variety of models for the atmosphere (known as the Tropospheric, Coastal, Maritime, and Urban models) and computes the scattering properties of each of these models using a multiple-scattering model with both Rayleigh and Mie scattering. The complete algorithm is described in the [MODIS Normalized Water-Leaving Radiance Algorithm Theoretical Basis Document \(ATBD\)](#) (a PDF document) authored by Howard R. Gordon and Kenneth Voss. Menghua Wang also participated in the development of this algorithm.

Atmospheric correction: Whitecaps

The MODIS algorithm also features a correction for *whitecaps*, the surf that forms on oceanic waves in the wind. Whitecaps alter the amount of light that is reflected off the ocean surface. If the wind is blowing, the amount of light reflected off of whitecaps can represent a large amount of the total light emitted from the surface of the ocean. This image shows what whitecaps on the ocean surface can look like.



Image courtesy of Jeff Johnson

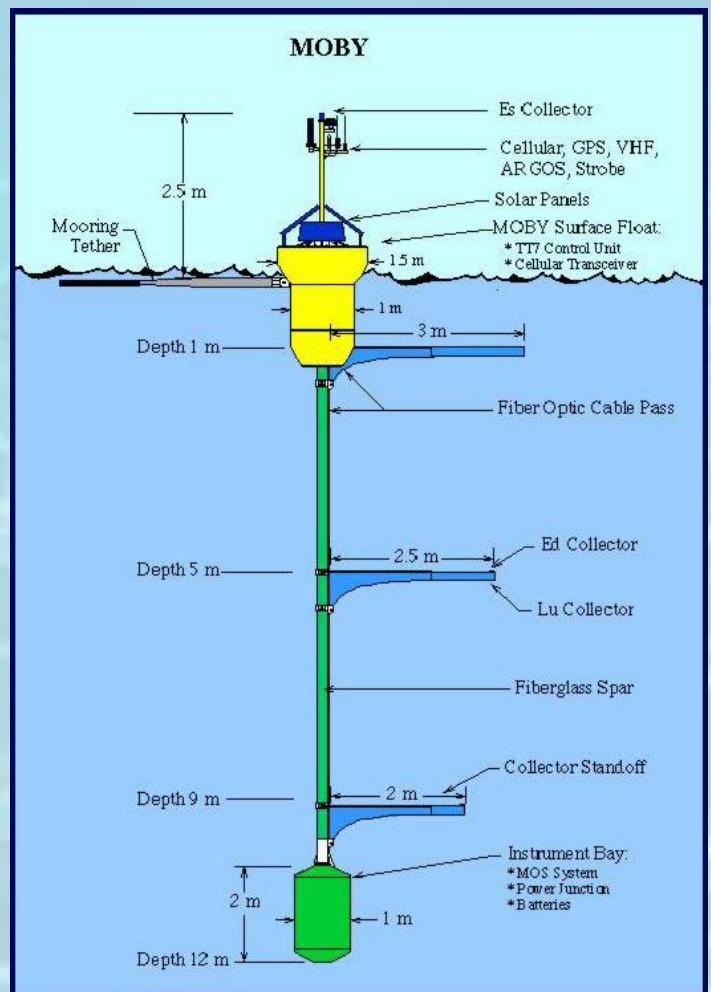
Of course, waves and whitecaps can sometimes get bigger than that.



Image courtesy of
Mitchell Silver,
maui2000.com

Data validation: The Marine Optical Buoy (MOBY)

The best way to determine if the algorithms being applied to the data measured by satellite ocean color sensors are accurate is to determine the actual water-leaving radiance at the surface of the ocean, and then compare this value to the satellite measurement. For the SeaWiFS and MODIS missions, this has been accomplished by a remarkable ocean-going instrument named the Marine Optical Buoy, or MOBY, which is moored in the calm waters near the island of Lanai, Hawaii.



MOBY is a complex instrument, but the concept of its operation is simple. Using a spectrometer (housed in the instrument bay at the bottom of the buoy), it measures the downwelling irradiance (meaning the amount of sunlight entering the ocean) and the upwelling radiance (meaning the scattered light that is reflected back to, and out of, the ocean surface) at three different depths: 1, 5, and 9 meters below the ocean surface. These measurements are then integrated to calculate the water-leaving radiance at the surface, and with an appropriate solar zenith angle correction, fairly simple when the measurements are made at noon, the measurements are converted to normalized water-leaving radiance. So when MODIS or SeaWiFS views the MOBY site and the normalized water-leaving radiance is calculated, the satellite value can be compared to the MOBY value. MOBY data has been critical to the remarkable calibration efforts performed by the MODIS Oceans team.

Summary

That, briefly and qualitatively, is a short description of how the radiance values measured by satellite radiometers are algorithmically transformed into normalized water-leaving radiances. It is interesting to realize that in the era of the CZCS, these pixel-by-pixel calculations required hours to complete for each CZCS scene, for algorithms much cruder than those in use today. The rapid pace of improvement in computational technology means that these calculations can now be performed in minutes on personal computers for scenes much larger than the original CZCS two-minute scenes.

The link to a private Web site is provided for informational purposes only and should not be construed as a NASA endorsement of services or products provided by a private vendor.

Acknowledgment

Dr. Menghua Wang and Dr. Howard Gordon provided helpful reviews of this *Science Focus!* article.

Links

[MOBY at Moss Landing Marine Laboratories \(MLML\)](#)

[Influence of oceanic whitecaps on atmospheric correction of ocean-color sensors \(Abstract\)](#)